

DIGITAL PROTECTION OF EHV LINES USING DECENTRALIZED APPROACH

**A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY**

**By
GANDE THIRUPATHAIAH**

**to the
DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR
MAY, 1982**

dedicated to

my parents

1952

4 JUN 1984

EE-1982-M-THI-DIG

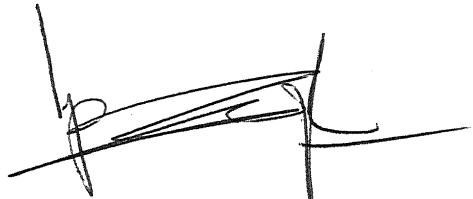
CENTRAL LIBRARY

Kanpur.

Acc. No. A 82721

CERTIFICATE

This is to certify that the work titled 'DIGITAL PROTECTION OF EHV LINES USING DECENTRALIZED APPROACH' reported in this thesis by G. Thirupathaiah has been carried out under my supervision and this work has not been submitted elsewhere for a degree.



Dr. L.P. Singh
Professor
Department of Electrical Engineering
Indian Institute of Technology
Kanpur.

POST GRADUATE OFFICE

This thesis has been approved
for the award of the degree of
Master of Technology (M.Tech.)
in accordance with the
regulations of the Indian
Institute of Technology Kanpur
Dated.

ACKNOWLEDGEMENTS

I am greatly indebted to Dr. L.P. Singh for suggesting the problem and providing his valuable guidance and encouragement throughout this work.

I am grateful to Shri K.V. Desikachar for timely and fruitful discussions.

I am thankful to my friends S/Shri V.P. Deshmukh, M.V. Govind and A.R. Shalu for their kind assistance. My thanks are due to Shri A. Ramgopal for proof-reading of the manuscript and also to other friends who helped in one or the other way while completing this work.

I thank Mr. C.M. Abraham for his excellent job in typing the manuscript.

GANDE THIRUPATHAIAH

ABSTRACT

EHV/UHV transmission systems need a reliable, fast, efficient and low cost protective relaying schemes in order to transmit power continuously with high reliability and stability. Protection scheme using electromechanical relays has numerous disadvantages and hence they were replaced in the beginning by electronic relays and finally by solid state relays. Although these solid state relays are successful in operation, they have certain distinct disadvantages such as lack of flexibility and absence of self testing (in off-line and on-line) etc. These disadvantages have resulted in a trend towards the use of programmable equipment in place of hardwired systems. Complex threshold characteristics can be obtained with lesser complexity and efforts with the help of programmable equipment.

In this thesis, a review of various methods using digital protection algorithms and design approaches for transmission line protection are outlined. A 3-zone Mho relay with blinders has been realized using decentralized approach based on fundamental frequency signals algorithm on INTEL 8080 microcomputer as it is commonly available and at the same time it provides programmable logic at low costs.

TABLE OF CONTENTS

	Page
LIST OF PRINCIPAL SYMBOLS	
LIST OF FIGURES	
Chapter 1 INTRODUCTION	1
1.1 Motivation	1
1.2 Problem definition	2
1.3 Historical review	2
1.4 Outline of the Chapters	4
Chapter 2 DIGITAL PROTECTION	5
2.1 Summary	5
2.2 Merits of digital protection	5
2.3 Algorithms for digital protection of transmission lines	6
2.3.1 Transmission line protection based on the system parameters	6
2.3.2 Transmission line protection based on the fundamental frequency signals	9
2.3.3 Transmission line protection based on the signal containing both fundamental and transient frequencies	12
2.3.4 Accuracy of above algorithms	12
2.4 Digital relaying systems	13
2.4.1 Centralized approach	13
2.4.2 Decentralized approach	14
2.4.3 Integrated approach	15

	Page
Chapter 3	
PROPOSED RELAYING SCHEME	17
3.1 Introduction	17
3.2 Theory of the proposed relaying scheme	17
3.3 System block diagram and descriptions	19
3.4 System software	21
3.5 Mathematical formulation	21
3.6 Results	28
Chapter 4	
CONCLUSIONS	51
4.1 Discussion of the results	51
4.2 Scope of the further work in this area	52
REFERENCES	53
APPENDIX A	
TRAPEZOIDAL RULE	56
APPENDIX B	
TRANSMISSION LINE DATA	59
APPENDIX C	
DATA-ACQUISITION SYSTEM	60

LIST OF PRINCIPAL SYMBOLS

V	system line to line voltage in volts
I	system line to line current in amps
Z	line impedance seen by relay
r_1, r_2, r_3	radii of zone 1, zone 2 and zone 3 circles
R_{c1}, R_{c2}, R_{c3}	cut-off resistances
K_b	slope of blinder
R	resistance of line seen by relay
X	reactance of line seen by relay
V_d, I_d	direct axis components of V and I respectively
V_q, I_q	quadrature axis components of V and I respectively
ϕ	phase angle
R_1', X_1'	positive sequence, resistance and reactance of transmission line
R_0, X_0	zero sequence, resistance and reactance of transmission line
Y_c	shunt capacitance of transmission line

Other symbols have been defined in the text as and when they occurred.

LIST OF FIGURES

Fig. No.	Caption	Page
1	3-zone Mho relay with blinders	18
2	System block diagram	20
3	Flow chart of proposed relaying scheme	26
4	Trapezoidal rule	57
5	Block diagram of a data acquisition system	57
6	Circuit diagram for data acquisition system	61
7	Waveforms related to data acquisition system	62

ABBREVIATIONS

SHC	sample and hold circuit
ADC	analog-to-digital converter
ROM	read only memory
RAM	random access memory
I/O	input/output port
CB	circuit breaker
CVT	capacitor voltage transformer
PT	potential transformer
CT	current transformer
CPU	central processing unit

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

The demand for electrical energy has become an ever increasing phenomenon because of continuous increase in population and industrialization. This has forced power utilities to generate and transmit more power at higher and higher voltages, over a long distances, as they could not get large power generation facilities locally. Evidently this increases over all cost and create stability problems. Therefore, to get maximum benefit, the system should be operated efficiently, stably and economically. To achieve this goal perfect and reliable protective relaying schemes are needed. That is, protection schemes should be capable of making quick and accurate decisions with high reliability and at lower costs. Digital protection schemes are well ahead in this direction since programmable equipments are of self checking nature and fast responding type. Using programmable equipment it is possible to realize more complex characteristics with less complexity in logic.

The continuous development in the field of micro-processors has made it possible to use them in power system network problems. Microprocessors provide programmable logic at low costs. This has led protection engineers to use

microcomputers in protection and other related areas which traditionally are the domains of analog devices.

1.2 PROBLEM DEFINITION

In a power system network, voltage and current varies on account of short circuits, sudden load disturbances etc. The relay continuously senses voltage and current at its location and determines whether fault has occurred. If fault occurs, it gives a signal to its Circuit Breaker to disconnect that particular element from the rest of the system and therefore, the relay performs three functions, viz.

1. Sensing the fault
2. Finding the location of fault
3. Giving trip signal to CB .

By introducing a microcomputer, we can relieve the relay from its first two functions so that fast clearing of fault along with greater reliability and security can be achieved, since programmable equipment is always self checking.

In this thesis, a three-zone Mho relay with blinders has been realized on INTEL 8080 microcomputer and tested for a sample system.

1.3 HISTORICAL REVIEW

Protective relay which functions as a sensing device, plays an important role in order to provide customers consistent and reliable power supply. In the early days,

power utilities used overcurrent relays for protecting transmission lines, but due to its inherent demerits such as shifting of balance point with the type of fault, change in generation and switch on or switch off operations, overcurrent relays are being replaced by distance relays such as plane impedance relay, angle impedance relay (i.e. ohm relay), angle admittance relay (i.e. Mho relay), reactance relay, offset-Mho relay, modified Mho relay etc.

In the beginning relays were of electromechanical type; but due to their inherent disadvantages such as high burden, high operating time, contact problems, sensitive to vibrations and shocks etc., they were gradually replaced by electronic relays which were free from the most of those disadvantages.

However, with the advent of solid state components, electronic relays were replaced by solid state relays, because of its additional advantages of compactness, reliability, and at the same time, they don't require high voltage power supplies.

Although the present protection schemes are successful in application, they suffer from a number of disadvantages including lack of flexibility, duplication of specification effort, adaptability to system changing conditions, exclusion of self testing (in off-line and on-line) facilities due to complexity and cost. These disadvantages have

resulted in a trend towards the use of programmable equipment in place of hardwired systems.

Implementation of digital relaying was first thought of by G.D. Rockfeller [1] in 1969. Effort was made to predict the peak fault voltage and current and hence, fault impedance was calculated by taking a few samples at the initial stage of fault by B.J. Mann et al. [2]. Several algorithms were developed and tried by Ranjabar et al. [3] and others. In 1977, Yoshiteru Miki [4] realized Mho and reactance relay characteristics and thus gave a new dimension to protection engineers in digital relaying field. Since then, every effort is being made to develop such software in order to make the system simple and reliable [6,7,8].

1.4 OUTLINE OF THE CHAPTERS

In Chapter 2, merits of digital protection are given. In addition to this, the different methods used in algorithms for protection of transmission lines using digital computer are discussed. Different types of digital protection systems based upon their hardware implementations have also been discussed briefly.

Chapter 3 deals with the theory and mathematical formulation including the algorithm for the digital simulation of the proposed relaying scheme and finally Chapter 4 concludes with the discussion of the result and scope of further work in this area.

CHAPTER 2

DIGITAL PROTECTION

2.1 SUMMARY

In this chapter merits of digital protection are discussed briefly. Overview of the digital relaying algorithms for the protection of transmission lines is given. Philosophies used in designing digital relaying systems such as centralized, decentralized and integrated approaches are outlined.

2.2 MERITS OF DIGITAL PROTECTION

Since computer based protection is of self-checking nature and any fault during the idling period is also automatically detected and therefore, reliability of such scheme is very high. Besides this, the digital protection has the following merits.

1. Possibility to realize sophisticated threshold characteristics of relays
2. Easy to change the settings for alterations in system conditions
3. Ability to check correctness of input and data missing or incorrect informations
4. Interfacing with other controlling devices is possible

5. Less maintenance is required
6. It reduces relay types, spare parts and documentation
7. To use processing capability of microprocessor, we can write more software instead of having more analog devices
8. It can give fault reports without specially designed devices, for post fault analysis.

2.3 ALGORITHMS FOR DIGITAL PROTECTION OF TRANSMISSION LINES

This section deals with the survey, classification and comparison of digital relaying algorithms for transmission line protection. Distance relays evaluate the line impedance by looking in to the transmission lines. The basic approaches being used in digital transmission line protection are of three types. These approaches are classified based on the form of the input signals which are used to make relaying decisions, and they are as follows :

1. Transmission line protection based on the system parameters
2. Transmission line protection based only on the fundamental frequency signals
3. Transmission line protection based on the signals containing both fundamental and transient frequencies.

2.3.1 Transmission Line Protection Based on the System Parameters

This assumes representation of a line by a set of

differential equations. The most common model of a transmission line is described by the following differential equation.

$$v = Ri + L \frac{di}{dt} \quad (2.1)$$

The above representation of a transmission line recognizes the D.C. offset as a valid part of the solution and therefore, no special features have to be implemented to suppress the D.C. offset. Calculated values of R and L using eqn. (2.1) are used for phase distance and ground distance relaying. The set of equations is manipulated depending upon the type of fault and the final equation obtained is of the form (2.1). However, in actual practice it contains some combination of voltage and current phase values to form v and i given in equation (2.1).

A number of algorithms have been suggested to solve equation (2.1) numerically. In 1971, McInnes et al [5] proposed an algorithm for this purpose. It proposed integration over two successive time intervals, so that a sufficient number of equations are obtained to solve R and L. Integral equations are solved numerically using the trapezoidal rule. The final expressions for R and L takes the form,

$$R = \frac{(v_{k-1} + v_k)(i_{k-1} - i_{k-2}) - (v_{k-1} + v_{k-2})(i_k - i_{k-1})}{(i_{k-1} + i_k)(i_{k-1} - i_{k-2}) - (i_{k-1} + i_{k-2})(i_k - i_{k-1})} \quad (2.2)$$

$$L = \frac{h}{2} \frac{(v_{k-1} + v_{k-2})(i_{k-1} + i_k) - (v_{k-1} + v_k)(i_{k-1} + i_{k-2})}{(i_{k-1} + i_k)(i_{k-1} - i_{k-2}) - (i_{k-1} + i_{k-2})(i_k - i_{k-1})} \quad (2.3)$$

where v and i are instantaneous values of voltage and current, k is the instant and h is the time interval.

However, it should be noted that there are several problems, associated with the characteristics of actual transmission lines which are not accounted in eqn. (2.1). This equation assumes perfectly transposed lines, and neither the shunt capacitance nor the capacitance used for series-compensation is considered. The fault resistance and effect of power flow on the line at the moment of fault are also not considered.

A number of techniques can be developed to cope with some of the problems mentioned before. A quite powerful technique is to filter the input signal with a lowpass filter, which enables the attenuation of the high frequency transients which are introduced by some of the effects mentioned above.

In 1975, Ranjbar et al [3] developed another technique which relates appropriate integration intervals of eqn. (2.1) to the particular harmonics that are selected for removal. The sampling rate is related as a multiple of the order of the harmonic to be removed, which makes the procedure quite restrictive by the sampling rate selection and accuracy.

2.3.2 Transmission Line Protection Based on the Fundamental Frequency Signals

This relies on the theory of orthogonal transforms [9]. The most widely used is the Fourier transform theory which utilizes the set of sine and cosine functions as an orthogonal set. Any function, then, can be represented as a sum of combinations of the functions from the defined orthogonal set. Basic properties of the Fourier transform can be used to extract any particular frequency component from the incoming signal. The expressions derived can be based on either the continuous or the discrete Fourier transform. In the case of the continuous functions, some form of numerical approximation is done to obtain a digital solution. Ramamoorthy [10] correlated samples of the input signals (voltage and current) with the stored samples of reference fundamental sine and cosine waves.

If the waveform expressions are given in rectangular form, then the general expression for the sine and cosine components of voltage for sample k are [11],

$$V_s = \frac{1}{N} \left[2 \sum_{l=1}^{N-1} V_{k-N+l} \sin \left(\frac{2\pi l}{N} \right) \right] \quad (2.4)$$

$$V_c = \frac{1}{N} \left[V_{k-N} + V_k + 2 \sum_{l=1}^{N-1} V_{k-N+l} \cos \left(\frac{2\pi l}{N} \right) \right] \quad (2.5)$$

where V_i are the voltage samples, N is the number of samples taken per fundamental cycle and subscripts s and c denotes sine and cosine components of signal, and i is variable.

From (2.4) and (2.5) magnitude of voltage is

$$V = (V_s^2 + V_c^2)^{\frac{1}{2}} \quad (2.6)$$

and the phase angle is

$$\phi_V = \tan^{-1}(V_s/V_c) \quad (2.7)$$

Similarly, for current signal,

$$I = (I_s^2 + I_c^2)^{\frac{1}{2}}$$

and

$$\phi_I = \tan^{-1}(I_s/I_c)$$

Then the expression for the impedance is,

$$Z = |Z| \angle \phi_Z$$

where

$$|Z| = [(V_s^2 + V_c^2) / (I_s^2 + I_c^2)]^{\frac{1}{2}} \quad (2.8)$$

and

$$\phi_Z = \tan^{-1}(V/I) \quad (2.9)$$

If the calculated values of Z and φ_Z using equations (2.8) and (2.9) exceed the settings, this determines the relaying action.

In the past couple of years, a number of techniques similar to the basic algorithm have been introduced. One approach to improve the time response of the algorithm is to reduce the data window to one-half of a cycle [12], which changes the limits on expressions (2.4) and (2.5). This introduces additional errors due to DC offset and high harmonics, but the scheme can be made quite acceptable by using various methods for compensation of the error sources [12]. The one-half cycle scheme is particularly efficient computationally when 12 samples per cycle are used because of certain symmetries of the Fourier coefficients.

There are other orthogonal function-sets which can be used to extract the fundamental frequency signal from the faulted signal. One of the first methods proposed for digital relaying is the use of sine and cosine functions and the derivatives as the orthogonal set [2]. A sinusoidal curve fit could be performed when the incoming data are used directly to calculate apparent resistance and reactance to the fault. Samples of voltage and currents are used to perform the fundamental sinusoidal component fit [15].

2.3.3 Transmission Line Protection Based on the Signals Containing Both Fundamental and Transient Frequencies

This employs two basic techniques, one assumes that the signal can be modelled with an expression containing both fundamental signal and high frequency components. The assumed expression contains unknown parameters which can be determined by least square technique. Incoming samples are used for the fitting process. Other technique uses waveforms which are obtained directly from the transmission lines and contain high frequency components. These are travelling waves. Travelling wave equations can be obtained from the transmission line model using distributed parameters.

2.3.4 Accuracy of Above Algorithms

It was concluded [11] that, in general, any of the algorithms is perfectly accurate when assumptions from which it is generated are considered. However, the smaller the data window is, the larger the errors are : The differential equation algorithms are quite accurate if approximately one-half of a cycle of data is used. The Fourier transform algorithms are the most accurate [11] after one cycle of the available data. The travelling wave algorithms have very quick response and are quite accurate.

In this thesis Fourier transform algorithm is used to realize 3-zone angle admittance (i.e. Mho) relay with blinders.

2.4 DIGITAL RELAYING SYSTEMS

There are three major approaches in the system developments which are related to the basic hardware implementations. They are :

1. Centralized approach
2. Decentralized approach
3. Integrated approach

2.4.1 Centralized Approach

This approach uses a minicomputer to implement most of the protection functions. The first prototype system PRODAR 70, was developed in a joint effort by Pacific Gas and Electric Company and the Westing House Electric Corporation in 1971 [14]. The system was minicomputer-based and all of the basic protection functions needed in a HV substation were implemented. Also, in the early 1970's, the American Electric Power Service Corporation (AEP) initiated a joint project with the IBM Corporation to develop a minicomputer-based relaying and data acquisition system. This project resulted in a prototype system which was field tested and the results were published in 1976 [12]. In 1973, the General Electric Company (GEC) started a project to develop a minicomputer based distance relay, which was further extended to include a pilot scheme having a digital system at each terminal of the transmission line to be protected.

Field tests for this system were completed in 1978 and the results were published, in 1979 [16]. Minicomputer based relay design activities were initiated at the University of New South Wales in 1970 [17].

The final conclusions of the projects indicated that the idea of a centralized protection system was feasible, but in order to achieve a flexible and sufficiently fast relaying function, a very fast and powerful computer should be considered. Evidently this will increase the cost. This led to the development of microcomputer based relays using decentralized approach.

2.4.2 Decentralized Approach

This approach uses a microprocessor to perform only one specific protection function. Based on it, several prototype developments and field testings were reported only recently. Its applications have been considered by several companies in Japan. For the past couple of years, prototype systems for microprocessor based distance relays were developed and field tested by the Mitsubishi Electric Corporation and the Kansai Electric Power Company, as well as by the Tokyo Electric Company and Toshiba Corporation. A software development for a transmission line protection relay was developed by Saskatchewan Power Corporation, Canada [6]. The systems which were field tested, performed satisfactorily compared to

the conventional relays. The reported systems were shown to be attractive both cost wise and performance wise, when compared to the conventional systems.

In this thesis this approach is used to realize a 3-zone Mho relay with blinders.

2.4.3 Integrated Approach

In this case, the protection functions are distributed to a number of microprocessors which are then connected in an integrated manner. There are two basic types of integrated systems : integrated protection systems, and integrated control and protection systems. So far only one integrated system has been built and tested by the Mitsubishi Electric Corporation and the Kansai Electric Power Company of Japan [19]. This is of the control and protection type. The integrated systems are capable of performing the relaying functions in parallel. Each dedicated microprocessor exhibits performance characteristics which are similar to that of decentralized approach. At the same time, the system integration concept, provides the additional benefits of extensive data acquisition and monitoring of the overall protection system. This feature is not available in the decentralized and conventional relaying systems and is considered quite relevant as far as the reliability, availability and maintenance of the relaying system is concerned. This approach requires only a moderate system price increase when

compared with the decentralized approach because of the communication subsystem. However, the integrated protection system offers optimization in design, because some duplication of hardware present in decentralized systems can be eliminated.

The benefits of integrated systems are numerous and include most of the benefits provided by the centralized and decentralized approaches. Some additional performance improvement is expected since the control and protection are combined and can be maintained and operated through a sophisticated man-machine interface.

CHAPTER 3

PROPOSED RELAYING SCHEME

3.1 INTRODUCTION

For phase faults, Mho relays with blinders are reliable, fast in operation and economical. In the proposed relaying scheme, a 3-zone Mho relay with blinders as shown in Fig.,1 has been developed and simulated on INTEL 8080 microcomputer. The proposed relaying scheme is suitable for on-line protection of EHV/UHV transmission lines.

3.2 THEORY OF THE PROPOSED RELAYING SCHEME

The method of transmission line protection used in this scheme is based on the fundamental frequency signals and approach is decentralized one. Here, the impedance of the transmission line is repeatedly calculated by taking the ratio of peak voltage and current. A digital computer sampling of sinusoidal waveform can determine the peak values as they occur.

This method relies on the Fourier transform theory. It should be noted that theoretically, this method promises the best accuracy because it utilizes the fundamental components only and all other components are rejected. This of course, assumes that the data are available for the full power cycle. However, at the moment of the fault, the expression for

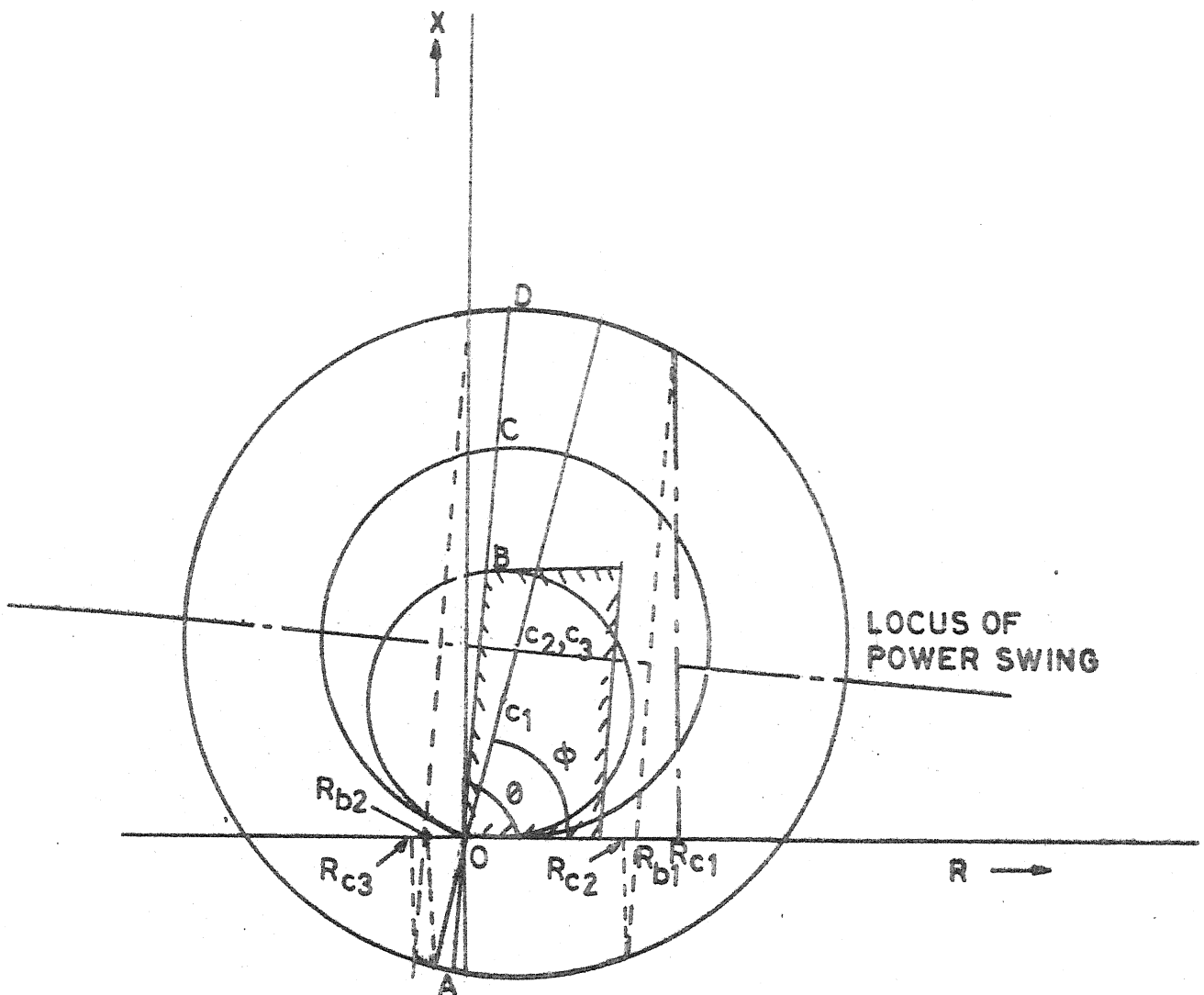


Fig.1 3-ZONE MHO RELAY WITH BLINDERS

impedance is not defined and any calculated value is an approximation. This approximation is a source of error, but it has been shown [11] that the error of the Fourier method is quite small in comparison with the errors of the other methods.

3.3 SYSTEM BLOCK DIAGRAM AND DESCRIPTIONS

System block diagram is shown in Fig. 2. Two continuous signals, one line to line voltage and the other delta current are supplied by transmission line to the CVT and main CT and then to the PT and auxiliary CT. PT provides isolation to sample and hold circuit (SHC) and analog-to-digital converter (ADC) and at the same time it converts the voltage to a range suitable for the ADC. Auxiliary CT provides the secondary line current which is then converted into the proportional voltage suitable for the ADC with the help of a suitable transactor. Auxiliary CT also provides isolation to SHC and ADC. Sample and hold circuit is to sample the voltage signals at regular intervals. Analog-to-digital converters convert these sampled signals into digital form which are then transmitted to microprocessor (CPU) through input ports 1,2 (one for voltage and the other for current). ROM contains program and constants of relay logic. RAM contains data and intermediate results. The processor processes the data according to program logic and gives appropriate tripping or blocking signal to the external circuit through output port.

For analog-to-digital conversion, a sampling rate of 8 samples per cycle (i.e., 400 samples per sec.) is chosen, which is good enough to nullify errors due to D.C. offset and harmonics.

3.4 SYSTEM SOFTWARE

After completion of the digitizing process, the two power system signals are stored into designated memory locations. After one set of sampled data is stored, the program routine starts calculating R,X and finding whether fault has occurred or not, while incoming status signals are received as a data word through ADC and buffer. If fault does not occur, it will shift samples by one and repeats the same process. The outgoing signals include trip and printer control. Printers are used for fault reports.

3.5 MATHEMATICAL FORMULATION

Let V and I are the relay quantities, where,

$V(V_{ab})$ is the fundamental component of voltage difference between phases a and b.

$I(I_a - I_b)$ is the fundamental component of delta current (i.e. difference of line current) of phases a and b.

Then, resolving them into components we get,

$$V = V_d + jV_q \quad (3.1)$$

$$I = I_d + jI_q \quad (3.2)$$

where subscripts d,q represent direct and quadrature axis components.

The impedance seen by the relay is

$$Z = \frac{V}{I} = \frac{V_d + jV_q}{I_d + jI_q} \quad (3.3)$$

$$= \frac{(V_d + jV_q)(I_d - jI_q)}{(I_d^2 + I_q^2)}$$

$$= R + jX \quad (3.4)$$

where

$$R = \frac{V_d I_d + V_q I_q}{I_d^2 + I_q^2}$$

and

$$X = \frac{V_q I_d - V_d I_q}{I_d^2 + I_q^2}$$

According to Fourier transform theory, direct and quadrature components of the voltage and current at the instant t can be expressed as,

$$V_d = \frac{2}{T} \int_t^{t+T} V(t) \sin wt \, dt \quad (3.5)$$

$$V_q = \frac{2}{T} \int_t^{t+T} V(t) \cos wt \, dt \quad (3.6)$$

$$I_d = \frac{2}{T} \int_t^{t+T} I(t) \sin wt \, dt \quad (3.7)$$

$$I_q = \frac{2}{T} \int_t^{t+T} I(t) \cos wt \, dt \quad (3.8)$$

where $V(t)$, $I(t)$ are the instantaneous values of voltage and current respectively at time t and T is the sampling period and is equal to the duration of one cycle.

Above integrals are calculated numerically using the trapezoidal rule given in Appendix A and final expressions for V_d, V_q, I_d and I_q are

$$V_d = \frac{1}{N} [V(t_0) \sin wt_0 + 2V(t_0+T/N) \sin w(t_0+T/N) + \dots] \quad (3.9a)$$

$$V_q = \frac{1}{N} [V(t_0) \cos wt_0 + 2V(t_0+T/N) \cos w(t_0+T/N) + \dots] \quad (3.9b)$$

$$I_d = \frac{1}{N} [I(t_0) \sin wt_0 + 2I(t_0+T/N) \sin w(t_0+T/N) + \dots] \quad (3.9c)$$

$$I_q = \frac{1}{N} [I(t_0) \cos wt_0 + 2I(t_0+T/N) \cos w(t_0+T/N) + \dots] \quad (3.9d)$$

where N is the number of intervals over a sampling period.

In the above equations the values of sine and cos terms are constants and stored in specified memory locations. Then using equations (3.9) and (3.4) R and X are calculated. The algorithm to simulate the proposed relaying scheme on microcomputer is given below. The following expressions are used in algorithm.

$$D_1 = (R-R_1)^2 + (X-X_1)^2$$

$$D_2 = (R-R_2)^2 + (X-X_2)^2$$

$$D_3 = (R-R_{33})^2 + (X-X_3)^2, \text{ where } R_{33} = r_3 + kr_3, \text{ where } k = \text{amount of off-set.}$$

$$k_1 = r_1^2; \quad k_2 = r_2^2; \quad k_3 = (r_3 + kr_3)^2$$

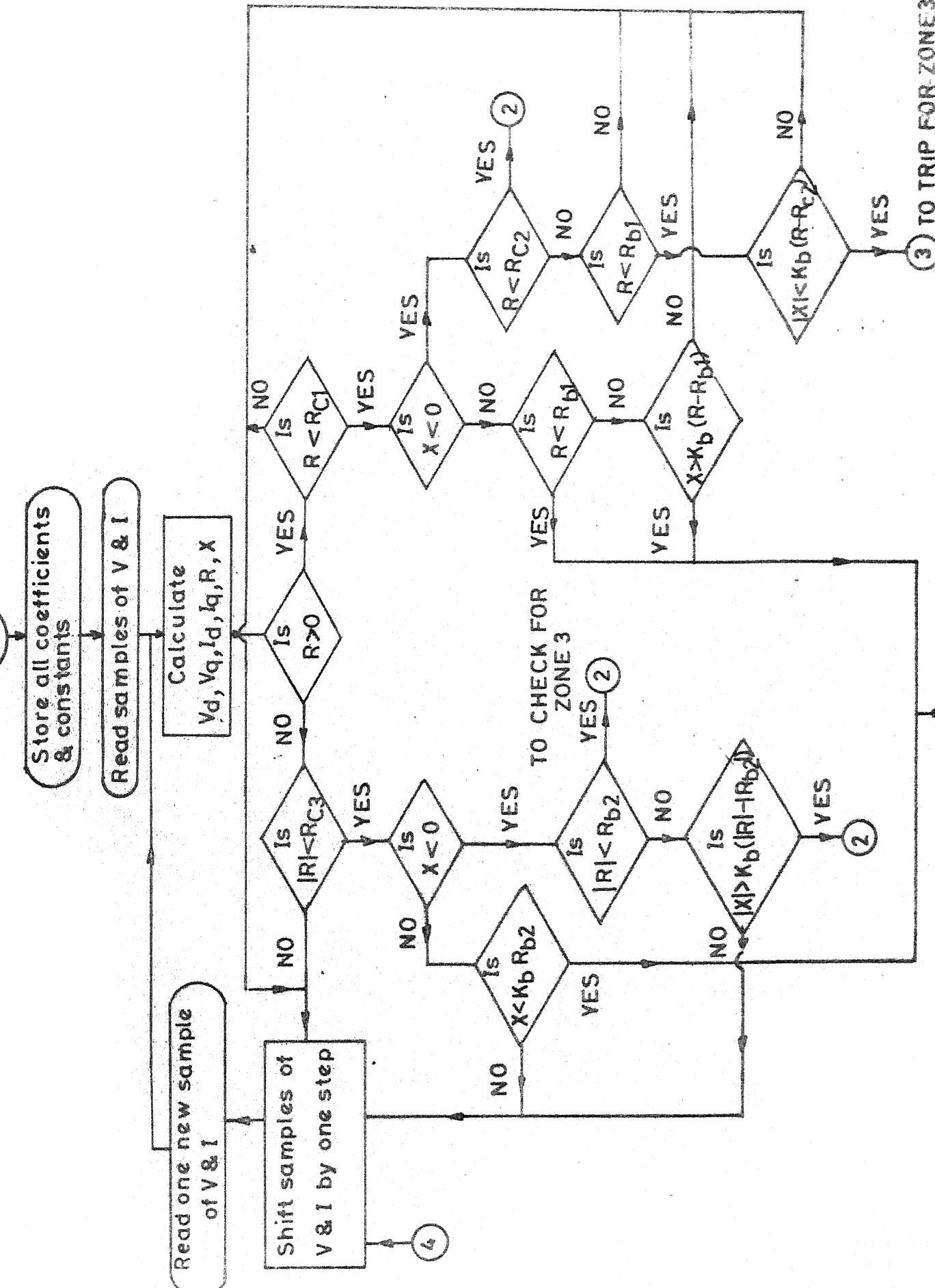
where R_i, X_i are centres of circles for different zones.

r_i are radii of circles and i is a variable.

Algorithm to Simulate Proposed Relay on Microcomputer :

1. Store all constants pertaining to relay logic in specified memory locations.
2. Read samples of voltage and current and store them in specified memory locations.
3. Calculate V_d, V_q, I_d, I_q, R and X using equations (3.9) and (3.4).
4. Check whether $R > 0$, if yes continue else go to Step 12.

5. Check whether $R < R_{c1}$, if yes continue else go to Step 26.
6. Check whether $X < 0$, if yes go to Step 9 else continue.
7. Check whether $R < R_{b1}$, if yes go to Step 17 else continue.
8. Check whether $X > k_b(R - R_{b1})$ if yes go to Step 17 else go to Step 26.
9. Check whether $R < R_{c2}$ if yes go to step 21 else continue.
10. Check whether $R < R_{b1}$ if yes continue else go to Step 26.
11. Check whether $|X| < k_b(R - R_{c2})$ if yes go to Step 26 else go to Step 26.
12. Check whether $|R| < R_{c3}$ if yes continue else go to Step 26.
13. Check whether $X < 0$ if yes continue else go to Step 16.
14. Check whether $|R| < R_{b2}$ if yes go to Step 21 else continue.
15. Check whether $|X| > K_b(|R| - R_{b2})$ if yes go to Step 21 else go to Step 26.
16. Check whether $X < K_b R_{b2}$ if yes go to Step 17 else go to Step 26.
17. Calculate D_1 .
18. Check whether $D_1 < k_1$ if yes go to Step 23, else continue.
19. Calculate D_2 .
20. Check whether $D_2 < k_2$ if yes go to Step 24, else continue.
21. Calculate D_3 .
22. Check whether $D_3 < k_3$ if yes go to Step 25, else go to Step 26.



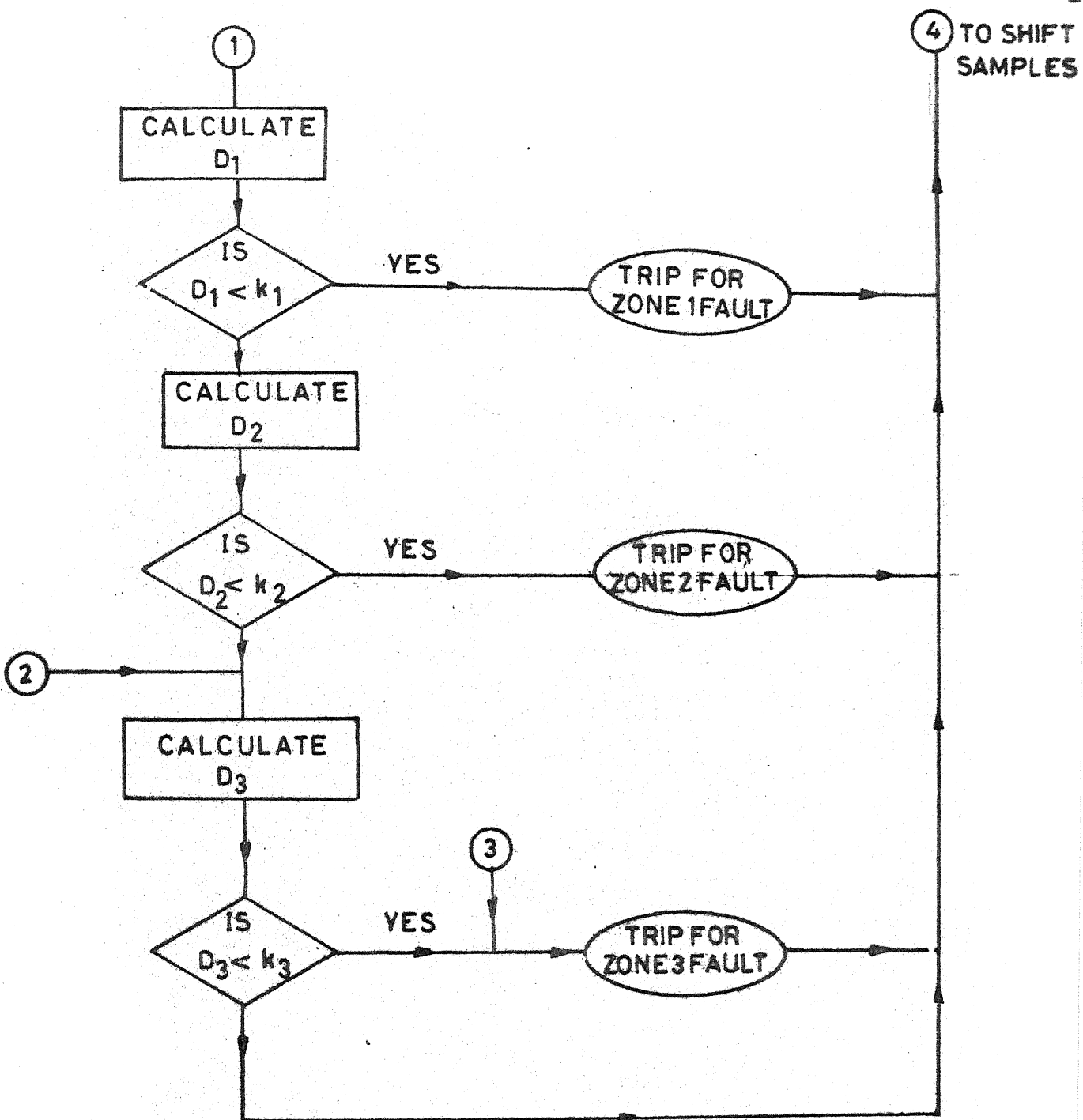


Fig.3 FLOW CHART OF PROPOSED RELAYING SCHEME

23. Trip for zone one fault, go to Step 26.
24. Trip for zone two fault, go to Step 26.
25. Trip for zone three fault.
26. Shift samples by one step.
27. Read one new sample of V and I.
28. Go to step 3.

The flow chart corresponding to the above algorithm is given in Fig. 3.

3.6 RESULTS

The proposed scheme is applied to a sample power system network for which data is given in Appendix B. The processor has taken approximately 47,000 cycles. That is, if the clock frequency of microcomputer is 5 MHz, it will take an execution time of 9.4 msec which is less than half power cycle (i.e. 10 msec.). So, the relay will operate in less than a half cycle for fault in any of the three zones which is a special feature of the proposed scheme.

The program listing is given below.

CHAPTER 4

CONCLUSIONS

4.1 DISCUSSION OF THE RESULTS

The present work proposes a protection scheme which possesses all the merits of solid state relaying and at the same time better threshold characteristics which is required for the protection of EHV/UHV transmission lines. The proposed scheme is applied to a sample power system network for which data is given in Appendix B. To execute the program of the relay logic, processor has taken approximately 47000 cycles for each zone, i.e., if the clock frequency of microcomputer is 5 MHz, it will take an execution time of 9.4 msec, which is less than half power cycle, a desirable feature of the relay.

The proposed relaying scheme might prove its use for on-line protection of EHV/UHV transmission lines, since the actual cost of the relay based on the above theory, if manufactured, will be quite less as the cost of hardware is decreasing day by day.

The software is based on instruction set of INTEL 8080 microcomputer which is simulated on DEC system-1090 at IIT Kanpur.

CENTRAL LIBRARY
I. I. T., Kanpur.

Acc. No.

82721

4.2 SCOPE OF THE FURTHER WORK IN THIS AREA

The digital computer based relaying schemes for generator, transformer and bus protection can be developed. In addition to the voltage and current at the fundamental frequency, the other functions such as frequency can also be realized.

As far as the system developments are concerned, it is expected that the decentralized and integrated approaches can be explored further. The computer application for on-line protection may lead to an overall computer control of power system network in which a central computer will control all the components of power system such as MW, MVAR generating tie line flows, bus voltages, CB status, reservoir levels, etc.

REFERENCES

1. G.D. Rockfeller, 'Fault protection with digital computer', Trans. IEEE, PAS-88, No.4, 1969, pp 438-464.
2. B.J. Mann and I.F. Morrison, 'Digital calculation of impedance for transmission line protection', Trans. IEEE, PAS-90, No.1, Jan-Feb., 1971, pp 270-279.
3. A.M. Ranjbar and B.M. Corey, 'Improved method for the protection of high voltage transmission line', Trans. IEEE, PAS-94, No.2, March-April, 1975, pp 544-550.
4. Yoshiteru Miki, Yoshihiro Sano and Jun-KhiMakino, 'Study of high speed distance relay using microprocessor', Trans. IEEE, PAS-96, No.2, March-April, 1977, pp 602-613.
5. A.D. McInnes and I.F. Morrison, 'Real time calculation of resistance and reactance for transmission line protection by digital computer', Trans. Inst.Eng., Australia, EE7 (1971), pp 16-23.
6. P.W. Davell, 'A software design for a computer based impedance relay for transmission line protection', Trans. IEEE, PAS-99, No.1, Jan-Feb., 1980, pp 234-245.
7. W.J. Smolinski, 'An algorithm for digital impedance calculation using a single PI section transmission line model', IEEE Trans., PAS-98, 1979, pp 1546-1551.

8. Y. Akimoto et al., 'Microprocessor based digital relay application in TEPCO', Trans. IEEE, PAS-100, May 1981, pp 2390-2398.
9. G.S. Hope and V.S. Umamaheswaran, 'Sampling for computer protection of transmission lines', IEEE Trans., PAS-93, (1974) pp 1522-1534.
10. M. Ramamoorthy, A note on impedance measurement using digital computers, IEE-IERE Proc. (India), 9(6), (1971), pp 243-247.
11. J.G. Gilbert et al., The development and selection of algorithms for relaying of transmission lines by digital computers, in B.D. Russell and M.E. Council (eds.), 'Power System Control and Protection', Academic Press, New York, 1978, pp 83-127.
12. A.G. Phadke et al., 'A digital computer system for EHV substations: analysis and field tests, IEEE Trans., PAS-95 (1976) pp 291-301.
13. Conference on Power System Protection, 16-19 April 1980, Madras, India, vol. 3.
14. G.B. Gilcrest et al., 'High speed distance relaying using a digital computer, Part I - system description, IEEE Trans. PAS-91 (1972), pp 1235-1243.

15. J.G. Gilbert and R.J. Shovlin, High speed transmission line fault impedance calculation using a dedicated minicomputer, IEEE Trans., PAS-94 (1975), pp 872-883.
16. M.M. Chen et al., 'Field experience with a digital system for transmission line protection', IEEE Trans. PAS-98 (1979), pp 1796-1805.
17. B.J. Mann and I.F. Morrison, 'Relaying a three phase transmission line with a digital computer', IEEE Trans., PAS-90 (1971), pp 742-750.
18. Second International Conference on 'Developments in Power System Protection' held between 10-12 June, 1980, IEE Conference Publication Number 185.
19. K. Tanaka et al., 'Application of microprocessors to the control and protection system at substation', IEEE Trans., PAS-99 (1980), pp 344-351.
20. G. Thirupathaiah, A. Varshney, L.P. Singh, 'On-line digital protection using microcomputer - a decentralized approach', Accepted for presentation in National Conference on Planning Operation and Control of Large Scale Power Systems to be held on 24-25, June, 1982 at Annamalai University, Tamil Nadu, India.
21. Introduction to Microprocessors by A.P. Mathur - TMH Publishing Company Ltd., New Delhi.

APPENDIX A

TRAPEZOIDAL RULE

The problem of numerical integration is the numerical evaluation of a definite integral

$$J = \int_a^b f(x) dx$$

where a and b are given and f is a function given analytically,

Consider the Fig. 4. Let the samples are taken at uniform intervals. If the interval is small, then the area enclosed by two samples is approximately of quadrilateral form. Then the total area enclosed by the curve over a definite period a, b is

$$\begin{aligned} J &= \int_a^b f(x) dx \approx \frac{f(a) + f(x_1)}{2} \times h + \frac{f(x_1) + f(x_2)}{2} \times h \\ &\quad + \dots + \frac{f(x_{n-1}) + f(b)}{2} \times h \\ &\approx h \left[\frac{f(a)}{2} + f(x_1) + f(x_2) + \dots + f(x_{n-1}) + \frac{f(b)}{2} \right] \end{aligned}$$

where $h = \frac{b-a}{n}$, $x_0 (=a)$, $x_1, x_2, \dots, x_{n-1}, x_n (=b)$ are the end points of the intervals and n is the number of intervals in period $b-a$.

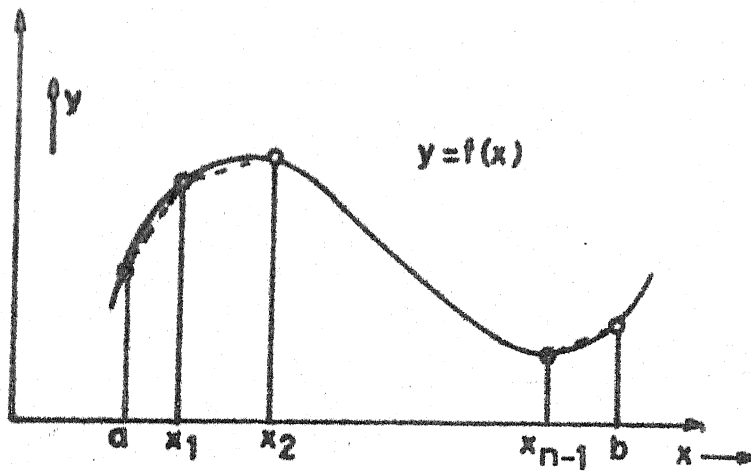


Fig.4 TRAPEZOIDAL RULE

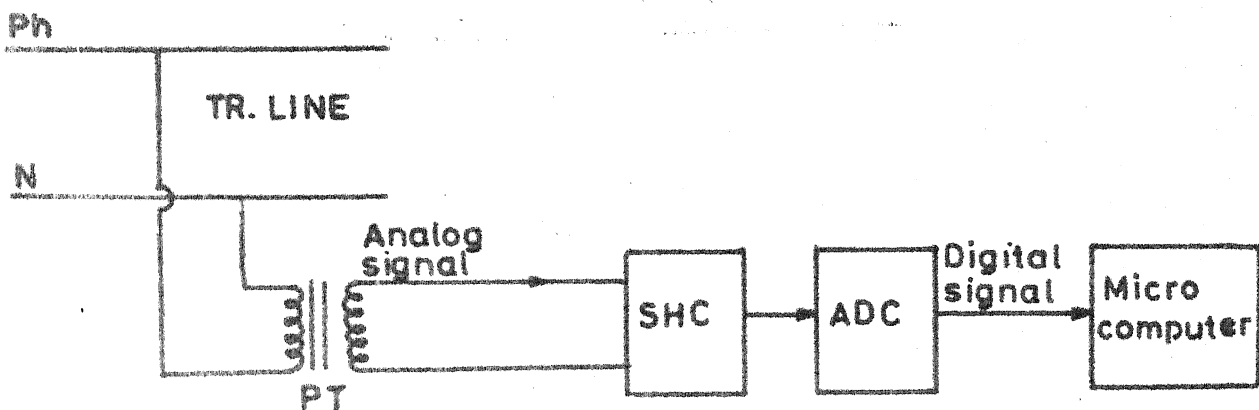


Fig.5 BLOCK DIAGRAM OF A DATA ACQUISITION SYSTEM ALONG WITH INPUT & OUTPUT SYSTEM

To find V_d, V_q, I_d and I_q numerically, we can apply this method as follows :

$$V_d = \frac{2}{T} \int_t^{t+T} V(t) \sin wt \, dt = \frac{2}{T} \times J$$

where T = time period = $b-a = nh$ and

$$J = \int_t^{t+T} V(t) \sin wt \, dt = \int_a^b f(x) \, dx$$

or

$$V_d = \frac{2}{n} \left[\frac{f(a)}{2} + f(x_1) + \dots + \frac{f(b)}{2} \right]$$

$$\text{Let } n = N ; \quad a = t_0 ; \quad x_1 = t_0 + \frac{T}{N}$$

$$x_2 = t_0 + \frac{2T}{N}$$

⋮

$$\text{and} \quad b = t_0 + \frac{NT}{N} = t_0 + T$$

Then,

$$\begin{aligned} V_d &= \frac{2}{N} \left[\frac{V(t_0) \sin wt_0}{2} + V(t_0 + T/N) \sin w(t_0 + \frac{T}{N}) + \dots + \right. \\ &\quad \left. \frac{V(t_0 + T) \sin w(t_0 + T)}{2} \right] \\ &= \frac{1}{N} [V(t_0) \sin wt_0 + 2V(t_0 + T/N) \sin w(t_0 + T/N) + \dots] \end{aligned}$$

which is same as equation (3.9a).

Similarly, we can write equations (3.9b), (3.9c) and (3.9d).

APPENDIX B

TRANSMISSION LINE DATA

The transmission line data which is used for testing software is as follows :

Line voltage	= 400 KV
Line length	= 400 KM
Line capacity	= 500 MW
R_1'	= 0.00812 PU
X_1'	= 0.0827 PU
R_o	= 0.06192 PU
X_o	= 0.23844 PU
$Y_c/2$	= 1.08142 PU
Base value	= 1000 MVA

APPENDIX C

DATA-ACQUISITION SYSTEM

SUMMARY

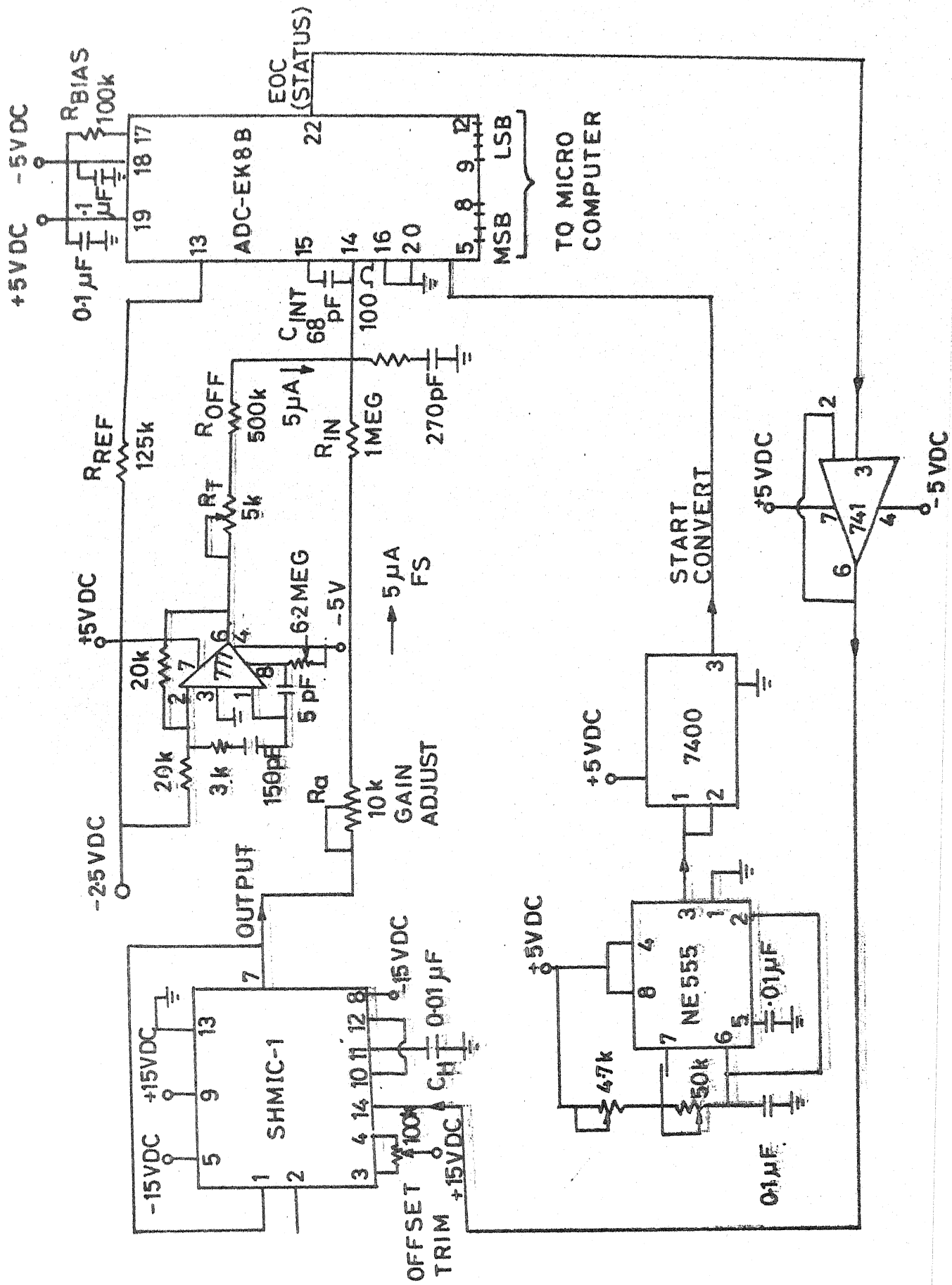
For using the proposed protection scheme on actual power system, the data should be available in digital form. This is done with the help of a data-acquisition system. In this Appendix, design, fabrication and testing of this is discussed briefly.

DATA-ACQUISITION SYSTEM (DAS)

A simple data acquisition system consists of sample-and-hold circuit (SHC) and analog-to-digital converter (ADC). The incoming analog signal is converted into a constant voltage over a short time interval by means of SHC. The constant output of SHC is converted into equivalent digital form by ADC for onward use. The block diagram of DAS is shown in Fig. 5. In the design of DAS, the following ICs are used.

1. NE555 : Timer for start convert pulse to ADC
2. SHMIC-1: Sample and hold IC
3. ADC-EK8B: Analog-to-digital converter IC

The actual circuit diagram is shown in Fig. 6.



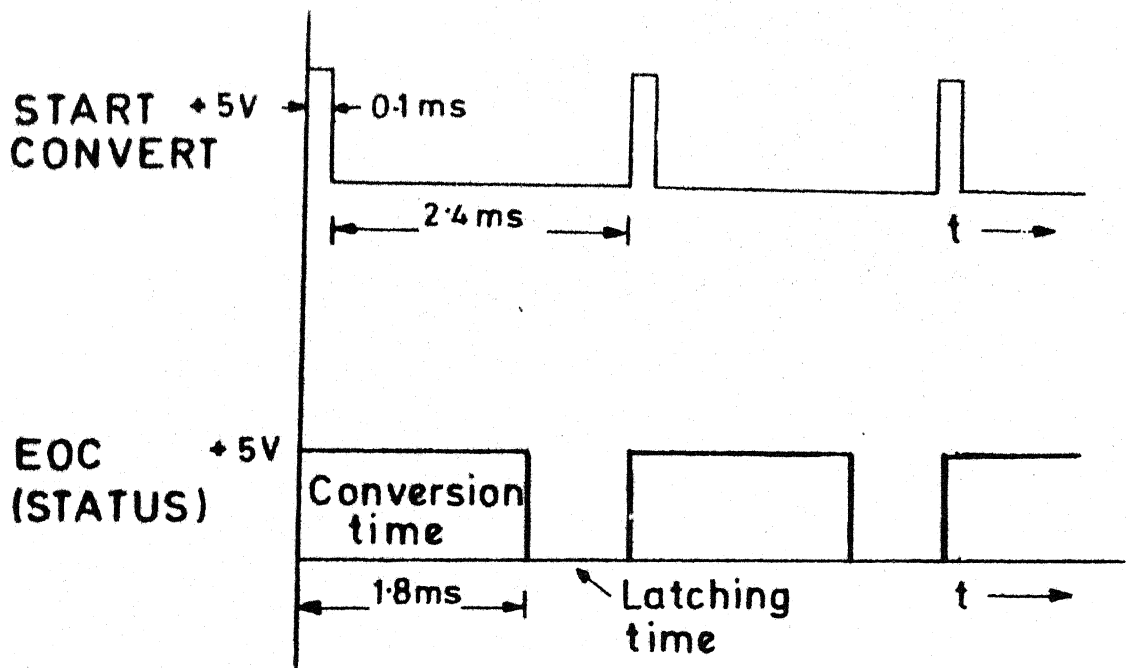


Fig. 7(a)

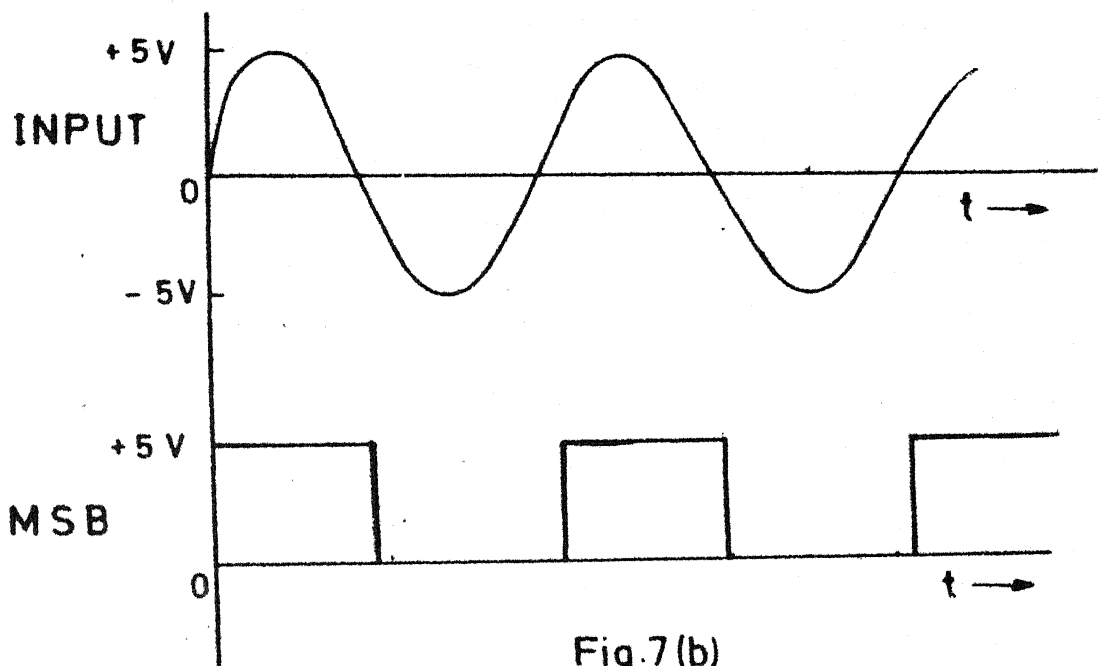


Fig. 7(b)

*Fig. 7 WAVEFORMS RELATED TO DATA ACQUISITION SYSTEM

The circuit is designed, fabricated and tested for $\pm 5V$ peak to peak sinusoidal waveform. The samples are taken at an interval of 2.5 msec. The different waveforms are shown in Fig. 7.

CIRCUIT OPERATION IN BRIEF

The start convert pulse (from timer) is given to ADC. The positive transition of start convert pulse triggers the ADC to start converting the previous sampled value into equivalent digital form, simultaneously., end of conversion status (EOC) is made high thereby putting the sampling circuit in hold mode (i.e., output of SHC is held constant in this period). After the completion of conversion, EOC is made low thereby putting the SHC in sampling mode (i.e., output of sample and hold circuit changes during this period) and during the same time digital data can be latched. Again, when the start convert pulse comes, same process is repeated.